AD-784 350

ASYMMETRIC GRAIN EVALUATION COMPUTER PROGRAM

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Aerojet Solid Propulsion Company

Prepared for:

Army Missile Command

28 June 1974

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FINAL REPORT

ASYMMETRIC GRAIN EVALUATION COMPUTER PROGRAM

Report 1163-FR-1

28 June 1974

Prepared under Sponsorship of:

U. S. Army Missile Command
Army Missile Research
Development and Engineering Laboratory
Propulsion Directorate
Redstone Arsenal, Alabama 35809

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FOREWORD

This report was prepared by Aerojet Solid Propulsion Company under Contract DAAH01-74-C-0434. Included herein is a summary of accomplishments during the contract effort. This work was administered under the direction of the Army Missile Research, Development and Engineering Laboratory of the U. S. Army Missile Command at Redstone Arsenal. The technical monitor of the program was Mr. A. Makut.

This program was performed by the Applied Mechanics and Dynamics Department of the Aerojet Solid Propulsion Company. Dr. R. B. Steele was Program Manager and Mr. A. L. Karnesky was the Technical Manager. Supporting the technical manager were Mr. M. J. Ditore, Technical Monitor, Mr. G. O. Chan, Grain Design Specialist, and Mr. N. R. Call, Computer Programming Specialist.

ABSTRACT

An existing computer program was modified to provide capability of evaluating the effects of solid propellant grain design asymmetrics caused by mandrel misalignment, and chamber bow or ovality. The computer code performs the necessary calculations to describe the regression history of an arbitrary singly perforated grain design. Modifications to the computer code consisted of adding supplemental subroutines to generalize the calculation scheme and to provide a plot display of grain periphery as a function of burn distance. A major effort was expended to define the respective grain and chamber wall periphery during a motor tailoff sequence.

Verification of the computer code was accomplished by evaluating three different grain geometries having various types of grain asymmetrics. These calculations demonstrated the operational characteristics and presented the grain geometric regression history of 60 cases.

Program documentation, including program code listing, card deck, and program tape, was provided to AMICOM as part of this contract.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION AND OBJECTIVE

The basic objective of the program was to provide the Army Missile Command with an analytical procedure capable of predicting the geometric regression history of a solid propellant grain that contains asymmetrics caused by mandrel misalignment, motor case bow, and ovality. This objective was accomplished by modifying an existing computer program that originally included the capability of evaluating regression history of arbitrary cross-sectional grain designs.

Essentially, the computer code is a generalized two-dimensional solution of the burning sequence of a singly perforated solid propellant grain cross-section, which is burning internally. The internal periphery may have any arbitrary contour specified by a series of coordinate points that describe the perimeter geometry. The motor case geometry may be circular, ellipitical or any arbitrary configuration; the latter being specified by a set of boundary coordinate points. Up to four different propellants may be considered with correspondingly different burning rates. The propellant interface geometrics are specified by another set of coordinate points that describes arbitrary interface geometries.

A more complete computer program description, including the various program options, is presented in the User's Manual (Reference 1). Results of verifying the modified computer code operational characteristics and capability of evaluating the influence of grain asymmetrics are contained in Reference 2.

The main purpose of this report is to describe the modifications of the original code and, in essence, contains the accomplishments of the contract effort.

II. PROGRAM CODE MODIFICATIONS

A. ORIGINAL PROGRAM CODE DESCRIPTION

The existing computer program was prepared using Fortran coding for the IBM 7094 during late 1960's. The program was originally intended as an analytical tool to evaluate the burning sequence of arbitrary two-dimensional grain configurations, burning in any describable burning rate field, resulting in a description of all subsequent periphery loci and cross-sectional area mass generation rates of the grain for each burn increment. The results were subsequently used in a ballistic program to define thrust and pressure-time history. The program was applicable to the analysis of at least four problems of interior ballistic grain analysis of (1) variable burning ratio, (2) off-center or misaligned mandrels, (3) three-dimensional grains and (4) the effects of burning (ablating) case wall insulation. The general approach was to generate the locus of points on the grain periphery at subsequent burn increments and eliminate any invalid locus point due to the nature of regressive grain element. A line segment between locus points describe the perimeter and consequent flow area.

B. MODIFICATIONS

Because of a change in computer facilities, the first modification of the computer code consisted of program conversion to the ISD 1108 computer. In addition the format statements were modified to be compatible with CDC 6600 computer. An existing plot subroutine was converted and added to the capability of the original program. The next effort consisted of debugging both the original code and the added plot subroutine. This was accomplished using simple grain geometries having different geometric configurations that would test the more important computer options.

During this initial effort additional capability was added to the program. A prime item was the analysis to define the perimeter of the exposed (chamber) boundaries for arbitrary propellant grain asymmetrics. Further, II.B. Modifications (cont)

propellant periphery and area summations for multiple propellants and the definition of minimum and maximum burn distance were added to the program calculation scheme.

Because one of the prime objectives of the program effort was to evaluate the effects of asymmetrics resulting from motor ovality, the program was modified to accept ellipitical motor case geometrics by simply specifying the dimensions of the major and minor axis. The capability to rotate the ellipitical geometry with respect to a set of grain locus points was also added to the code. The modification was subsequently extended to include an arbitrary motor case geometry that might be described, similar to the grain geometry, by a set of coordinate locus points.

For symmetrical initial grain geometries, the input requirements were reduced by considering quadrant symmetry. That is, only a description of the grain geometry in the first quadrant need be specified and the computer code was modified to generate the complete initial grain periphery in the remaining three quadrants.

A significant computer time saving device was added to the computer code. This consisted of the capability of calculating the periphery at variable burn distance (time step). Thus the user may select a variable time step best suited to his requirement or propellant burn back region of interest. This addition is particularly valuable in evaluating asymmetrics or grain configurations having slivers during tailoff. As an example this option allows selection of a relatively large initial calculation step size until the burning sequence approaches the outer boundaries (or other burn increment of interest such as propellant interfaces) after which the time step may be reduced to evaluate the effects of small anomalies in the motor case, propellant sliver or propellant interfaces. An important feature of this option is the reduction in computer time for those cases where the region of interest (such as asymmetrics) is localized to a particular burn increment sequence.

II. Program Code Modifications (cont)

C. PROGRAM VERIFICATION

As indicated previously, initial verification of the program capability was accomplished using arbitrarily selected grain geometries to test the accuracy of the calculations and important program options. Computer results were compared with hand calculation.

The major task of the contract was a formal verification of the computer code capability. The modified computer code was used to evaluate three different grain designs, supplied by AMICOM, having four general types of asymmetrics. The type and magnitude of asymmetrics are shown in Table 1. The complete matrix of 60 computer case runs selected for analysis is provided in Table 2. These were selected to demonstrate the calculated regression history at several axial stations to show the overall motor grain geometry at various burn distances. Computer output and plotted data for all 60 cases were submitted to AMICOM under separate cover. A description of the analysis and examples of the calculations and plotted data are presented in Reference 2. In summary, the results of this verification task successfully demonstrated the computer code capability to define the effects of small asymmetrics caused by mandrel misalignment, motor case bow, and ovality.

III. RESULTS AND CONCLUSIONS

An analytical (computerized) technique capable of predicting the geometric regression history of solid propellant grains containing asymmetrics was developed. The calculation procedures of an existing computer program were improved to reduce program input requirements and computer time. The added capability of the developed computer code should enhance future ballistic analyses by accurately describing the regression history of propellant grains that contain peculiarities in geometries.

III. Results and Conclusions (cont)

Documentation of the computer code, including a complete computer code listing, card deck, and program tape, was supplied by AMICOM.

The major recommendations made for further improvement consist of:

1. Include grain symmetry in the calculation scheme to reduce the amount of calculations required to describe the regression history and consequently, reduce computer time.

2. Provide the capability of describing the entire motor grain regression (rather than at discrete axial stations) in one computer run.

3. Combine this computer code with a ballistic program so as to provide thrust and pressure time history directly.

REFERENCES

1. User's Manual - "Asymmetric Grain Evaluation Computer Program," Report 1163-UM-1F, June 1974

2. <u>Asymmetric Grain Evaluation Computer Program - Analysis of Three Motor Grain Configurations</u>, Technical Report 1163-GA-1, May 1974

TABLE 1

MISALIGNMENT PARAMETRICS FOR TASK C

Case	Type	Plane of Misalignment	Amount
Base	None	- -	- -
1a	Ovality	Star Point	0.050 in. over full length
b	Ovality	Star Valley	0.050 in. over full length
2a	Bow	Star Point	0.060 in. at aft end
b	Bow	Star Valley	0.060 in. at aft end
3a	Mandrel displaced	Star Point	+0.050 in. head, +0.050 in. aft
b	Mandrel displaced	Star Valley	+0.050 in. head, +0.050 in. aft
c	Mandrel cocked	Star Point	+0.050 in. head, -0.050 in. aft
d	Mandrel cocked	Star Valley	+0.050 in. head, -0.050 in. aft

TABLE 2, Sheet 1 of 4

DESIGN 1 - FOUR POINT WAGON WHEEL TAPERED

Case	Grain Sequence Number	Computer Run Number	Motor Axial Station	Type	Plane of Misalignment	Amount
1	1	1	0.0	Base	None	None
	2	2	18.0	Base	None	None
	3	3	36.0	Base	None	None
1a	4	4	0.0	Ovality	Star Point	0.050
	5	5	18.0	Ovality	Star Point	0.050
	6	6	36.0	Ovality	Star Point	0.050
1b	7	7	0.0	Ovality	Star Valley	0.050
	8	8	18.0	Ovality	Star Valley	0.050
	9	9	36.0	Ovality	Star Valley	0.050
2a	(1)	10	0.0	Bow	None	0.000
	10	11	9.0	Bow	Star Point	0.010
	11	12	18.0	Bow	Star Point	0.020
	12	13	27.0	Bow	Star Point	0.030
	13	14	31.0	Bow	Star Point	0.050
	14	15	36.0	Bow	Star Point	0.060
2b	(1)	16	0.0	Bow	None	0.000
	15	17	9.0	Bow	Star Valley	0.010
	16	18	18.0	Bow	Star Valley	0.020
	17	19	27.0	Bow	Star Valley	0.030
	18	20	31.0	Bow	Star Valley	0.050
	19	21	36.0	Bow	Star Valley	0.060
3a	20	22	0.0	Mandrel Displaced	Star Point	0.050
	21	23	36.0	Mandrel Displaced	Star Point	0.050
3b	22	24	0.0	Mandrel Displaced	Star Valley	0.050
	23	25	36.0	Mandrel Displaced	Star Valley	0.050
3c	(20)	26	0.0	Mandrel Cocked	Star Point	0.050
	(2)	27	18.0	Mandrel Cocked	None	0.000
	(21)	28	36.0	Mandrel Cocked	Star Valley	0.050
3d	(22)	29	0.0	Mandrel Cocked	Star Valley	0.050
	(2)	30	18.0	Mandrel Cocked	None	0.000
	(23)	31	36.0	Mandrel Cocked	Star Valley	0.050

NOTE: ( ) = Replicates

TABLE 2, Sheet 2 of 4

DESIGN 2 - SLOT AND SHELL

Case	Grain Sequence Number	Computer Run Number	Motor Axial Station	Type	Plane of Misalignment	Amount
1	1	1	0.0	Base	None	None
	(1)	2	23.7	Base		None
	2	3	23.701	Base		None
	(2)	4	26.0	Base		None
	3	5	26.001	Base		None
	(3)	6	36.0	Base		None
1a	4	7	0.0	Ovality	None	0.050
	(4)	8	23.7	Ovality	None	0.050
	5	9	23.701	Ovality	None	0.050
	(5)	10	26.0	Ovality	None	0.050
	6	11	26.001	Ovality	Star Point	0.050
	(6)	12	36.0	Ovality	Star Point	0.050
1b	(4)	13	0.0	Ovality	None	0.050
	(4)	14	23.7	Ovality	None	0.050
	(5)	15	23.701	Ovality	None	0.050
	(5)	16	26.0	Ovality	None	0.050
	7	17	26.001	Ovality	Star Valley	0.050
	(7)	18	36.0	Ovality	Star Valley	0.050
2a	(1)	19	0.0	Bow	None	0.000
	8	20	12.0	Bow	None	0.010
	9	21	23.7	Bow	None	0.020
	10	22	23.701	Bow	None	0.020
	11	23	26.0	Bow	None	0.029
	12	24	26.001	Bow	Star Point	0.029
	13	25	31.0	Bow	Star Point	0.050
	14	26	36.0	Bow	Star Point	0.060
2b	(1)	27	0.0	Bow	None	0.000
	(8)	28	12.0	Bow	None	0.010
	(9)	29	23.7	Bow	None	0.020
	(10)	30	23.701	Bow	None	0.020
	(11)	31	26.0	Bow	None	0.029
	15	32	26.001	Bow	Star Valley	0.029
	16	33	31.0	Bow	Star Valley	0.050
	17	34	36.0	Bow	Star Valley	0.060

NOTE: ( ) = Replicates

TABLE 2, Sheet 3 of 4

DESIGN 2 - SLOT AND SHELL (cont)

Case	Grain Sequence Number	Computer Run Number	Motor Axial Station	Type	Plane of Misalignment	Amount
3a	18	35	0.0	Mandrel Displaced	None	0.050
	(18)	36	23.7	Mandrel Displaced	None	0.050
	19	37	23.701	Mandrel Displaced	None	0.050
	(19)	38	26.0	Mandrel Displaced	None	0.050
	(13)	39	26.001	Mandrel Displaced	Star Point	0.050
	(13)	40	36.0	Mandrel Displaced	Star Point	0.050
3b	(18)	41	0.0	Mandrel Displaced	None	0.050
	(18)	42	23.7	Mandrel Displaced	None	0.050
	(19)	43	23.701	Mandrel Displaced	None	0.050
	(19)	44	26.0	Mandrel Displaced	None	0.050
	(16)	45	26.001	Mandrel Displaced	Star Valley	0.050
	(16)	46	36.0	Mandrel Displaced	Star Valley	0.050
3c	(18)	47	0.0	Mandrel Cocked	None	0.050
	(1)	48	18.0	Mandrel Cocked	None	0.000
	20	49	23.7	Mandrel Cocked	None	0.016
	21	50	23.701	Mandrel Cocked	None	0.016
	22	51	26.0	Mandrel Cocked	None	0.022
	23	52	26.001	Mandrel Cocked	Star Point	0.022
	(13)	53	36.0	Mandrel Cocked	Star Point	0.050
3d	(18)	54	0.0	Mandrel Cocked	None	0.050
	(1)	55	18.0	Mandrel Cocked	None	0.000
	(20)	56	23.7	Mandrel Cocked	None	0.016
	(21)	57	23.701	Mandrel Cocked	None	0.016
	(22)	58	26.0	Mandrel Cocked	None	0.022
	24	59	26.001	Mandrel Cocked	Star Valley	0.022
	(16)	60	36.0	Mandrel Cocked	Star Valley	0.050

NOTE: ( ) = Replicates

TABLE 2, Sheet 4 of 4

DESIGN 3 - SIX POINT WAGON WHEEL

Case	Grain Sequence Number	Computer Run Number	Motor Axial Station	Type	Plane of Misalignment	Amount
1	1	1	0.0	Base	None	None
	(1)	2	36.0	Base	None	None
1a	2	3	0.0	Ovality	Star Point	0.050
	(2)	4	36.0	Ovality	Star Point	0.050
1b	3	5	0.0	Ovality	Star Valley	0.050
	(3)	6	36.0	Ovality	Star Valley	0.050
2a	(1)	7	0.0	Bow	None	0.000
	4	8	9.0	Bow	Star Point	0.010
	5	9	18.0	Bow	Star Point	0.020
	6	10	27.0	Bow	Star Point	0.030
	7	11	31.0	Bow	Star Point	0.050
	8	12	63.0	Bow	Star Point	0.060
2b	(1)	13	0.0	Bow	None	0.000
	9	14	9.0	Bow	Star Valley	0.010
	10	15	18.0	Bow	Star Valley	0.020
	11	16	27.0	Bow	Star Valley	0.030
	12	17	31.0	Bow	Star Valley	0.050
	13	18	36.0	Bow	Star Valley	0.060
3a	(7)	19	0.0	Mandrel Displaced	Star Point	0.050
	(7)	20	36.0	Mandrel Displaced	Star Point	0.050
3b	(12)	21	0.0	Mandrel Displaced	Star Valley	0.050
	(12)	22	36.0	Mandrel Displaced	Star Valley	0.050
3c	(7)	23	0.0	Mandrel Cock	Star Point	0.050
	(1)	24	18.0	Mandrel Cock	None	0.000
	(7)	25	36.0	Mandrel Cock	Star Point	0.050
3d	(12)	26	0.0	Mandrel Cock	Star Valley	0.050
	(1)	27	18.0	Mandrel Cock	None	0.000
	(12)	28	36.0	Mandrel Cock	Star Valley	0.050

NOTE: ( ) = Replicates